

"Express Mail" mailing label number EV 339 772 499 U.S.

Date of Deposit: October 7, 2003

Our Case No. 11549/14

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE  
APPLICATION FOR UNITED STATES LETTERS PATENT

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TITLE:

METHOD AND APPARATUS FOR  
ENABLING FAST CLOCK PHASE  
LOCKING IN A PHASE-LOCKED  
LOOP

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**METHOD AND APPARATUS FOR ENABLING FAST CLOCK PHASE  
LOCKING IN A PHASE-LOCKED LOOP**

**CROSS-REFERENCE TO RELATED APPLICATION**

This application claims priority of Taiwanese  
5 application no. 091123350, filed on October 9, 2002.

**BACKGROUND OF THE INVENTION**

**1. Field of the Invention**

The invention relates to a method and apparatus for  
clock phase locking in a phase-locked loop, more  
10 particularly to a method and apparatus for enabling fast  
clock phase locking in a phase-locked loop.

**2. Description of the Related Art**

Referring to Figure 1, a typical rewritable digital  
versatile disc (hereinafter referred to as DVD-RAM) 1  
15 is shown to include a plurality of adjacent header regions  
12 and record regions 11. Each header region 12 precedes  
a corresponding record region 11, and includes package  
headers and packet headers that describe data recorded  
in the corresponding record region 11. When reading  
20 binary data of digital signals recorded in the DVD-RAM  
1, clock phase locking of the digital signals must be  
performed first through a phase-locked loop. Referring  
to Figure 2, a typical phase-locked loop 2 is shown to  
include a phase detector 21, a charge pump 22 coupled  
25 to the phase detector 21, a loop filter 23 coupled to  
the charge pump 22, a voltage controlled oscillator (VCO)  
24 coupled to the loop filter 23, and a frequency divider

25 interconnecting the voltage controlled oscillator 24 and the phase detector 21. During operation, an input digital signal (IN) associated with the DVD RAM 1, together with a reference clock signal (CLK) from the frequency divider 25, are provided to the phase detector 21. When the reference clock signal (CLK) overruns the input digital signal (IN), the phase detector 21 either provides ascending pulses (UP) with narrower widths or descending pulses (DN) with wider widths to the charge pump 22. At this time, the charge pump 22 generates a positive current output ( $I_{cp}$ ) that is integrated by the loop filter 23 to result in a descending voltage ( $V_{ct}$ ) for controlling the voltage controlled oscillator 24 to lower the frequency of the reference clock signal (CLK) generated by the frequency divider 25. On the other hand, when the reference clock signal (CLK) underruns the input digital signal (IN), the phase detector 21 either provides ascending pulses (UP) with wider widths or descending pulses (DN) with narrow widths to the charge pump 22. At this time, the charge pump 22 generates a negative current output ( $I_{cp}$ ) that is integrated by the loop filter 23 to result in an ascending voltage ( $V_{ct}$ ) for controlling the voltage controlled oscillator 24 to raise the frequency of the reference clock signal (CLK) generated by the frequency divider 25. Therefore, through phase adjustment by the aforesaid phase-locked loop 2, the phase of the reference clock signal (CLK)

will gradually converge to that of the input digital signal (IN) such that the current output ( $I_{cp}$ ) eventually reaches zero, which indicates a locked clock phase condition.

5        Nevertheless, since the record regions 11 and the header regions 12 may have blank areas with no data recorded therein, such as areas 121, 122 in a header region 12 and areas 111, 112 in a record region 11 as shown in Figure 2, recorded areas of the DVD-RAM 1 are  
10       actually discontinuous such that the clock phase fluctuates irregularly when reading the DVD-RAM 1. As a result, the reference clock signal (CLK) from the frequency divider 25 will have a rather large phase difference with the input digital signal (IN), thereby  
15       requiring a relatively long amount of time for clock phase locking.

#### **SUMMARY OF THE INVENTION**

Therefore, the object of the present invention is to provide a method and apparatus for enabling fast clock  
20       phase locking in a phase-locked loop.

According to one aspect of the present invention, there is provided a method for enabling fast clock phase locking in a phase-locked loop. The phase-locked loop includes a phase detector for receiving an input digital  
25       signal associated with a rewritable digital versatile disc and an input phase-locking clock signal, and a voltage controlled oscillator that generates an

oscillator output. The method comprises the steps of:

in response to the oscillator output, obtaining multiple sampling points of the input digital signal, wherein temporally adjacent ones of the sampling points are spaced apart from each other by an interval;

comparing logic levels of each temporally adjacent pair of the sampling points to detect presence of a logic level transition in the input digital signal; and

providing an adjusted input phase-locking clock signal for replacing a current input phase-locking clock signal to the phase detector, the adjusted input phase-locking clock signal corresponding to one of the sampling points in the temporally adjacent pair that was detected to have the logic level transition occurring in the interval of the temporally adjacent pair.

According to another aspect of the present invention, there is provided a method for enabling fast clock phase locking in a phase-locked loop. The phase-locked loop includes a phase detector for receiving an input digital signal associated with a rewritable digital versatile disc and an input phase-locking clock signal, and a voltage controlled oscillator that generates an oscillator output. The method comprises the steps of:

in response to the oscillator output, generating a number (N) of sampling clock signals;

sampling the input digital signal at clock edges of the sampling clock signals to obtain multiple sampling

points of the input digital signal, wherein temporally adjacent ones of the sampling points are spaced apart from each other by an interval;

5       comparing logic levels of each temporally adjacent pair of the sampling points to detect presence of a logic level transition in the input digital signal; and

10       selecting one of the sampling clock signals that is to be provided to the phase detector as the input phase-locking clock signal, the selected one of the sampling clock signals having one of the clock edges thereof defining the interval that was detected to have occurrence of the logic level transition in the input digital signal.

15       According to yet another aspect of the present invention, there is provided an apparatus for enabling fast clock phase locking in a phase-locked loop. The phase-locked loop includes a phase detector for receiving an input digital signal associated with a rewritable digital versatile disc and an input  
20       phase-locking clock signal, and a voltage controlled oscillator that generates an oscillator output. The apparatus comprises a sampling clock generator, a detector unit, and a selector unit.

25       The sampling clock generator is adapted to receive the oscillator output from the voltage controlled oscillator, and generates a number (N) of sampling clock signals in response to the oscillator output.

The detector unit is coupled to the sampling clock generator and is adapted to receive the input digital signal. The detector unit samples the input digital signal at clock edges of the sampling clock signals to obtain multiple sampling points of the input digital signal. Temporally adjacent ones of the sampling points are spaced apart from each other by an interval. The detector unit further compares logic levels of each temporally adjacent pair of the sampling points to detect presence of a logic level transition in the input digital signal.

The selector unit is coupled to the sampling clock generator and the detector unit, and is controlled by the detector unit to select one of the sampling clock signals from the sampling clock generator. The selected one of the sampling clock signals has one of the clock edges thereof defining the interval that was detected by the detector unit to have occurrence of the logic level transition in the input digital signal. The selector unit is further adapted to provide the selected one of the sampling clock signals to the phase detector as the input phase-locking clock signal.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

Other features and advantages of the present invention will become apparent in the following detailed description of the preferred embodiment with reference to the accompanying drawings, of which:

Figure 1 is a schematic diagram to illustrate record regions and header regions of a conventional DVD-RAM;

Figure 2 is a schematic circuit block diagram of a conventional phase-locked loop employed during playback of the DVD-RAM of Figure 1;

Figure 3 is a schematic circuit block diagram showing the preferred embodiment of an apparatus according to the present invention, together with a phase-locked loop;

Figure 4 is a schematic circuit block diagram to illustrate a detector unit of the preferred embodiment;

Figure 5 is an exemplary waveform of an input digital signal associated with data recorded in a DVD-RAM;

Figure 6 is a timing diagram to illustrate the relationships of an input digital signal and exemplary sampling clock signals generated in the preferred embodiment; and

Figure 7 is a flowchart to illustrate the preferred embodiment of a method for enabling fast clock phase locking in a phase-locked loop according to the present invention.

#### **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT**

Referring to Figure 3, the preferred embodiment of an apparatus 5 according to the present invention is shown together with a phase-locked loop 4. The apparatus 5 enables the phase-locked loop 4 to lock the clock phase of an input digital signal ( $S_{DATA}$ ) associated with a



rewritable digital versatile disc in a relatively short amount of time. As described in the foregoing, the phase-locked loop 4 includes a phase detector 41 for receiving the input digital signal ( $S_{DATA}$ ) and an input phase-locking clock signal, a charge pump 42 coupled to the phase detector 41, a loop filter 43 coupled to the charge pump 42, and a voltage controlled oscillator (VCO) 44 that generates an oscillator output. Since the configuration and operation of the phase-locked loop 4 are well known in the art, a detailed description of the same is omitted herein for the sake of brevity.

As shown in Figures 3 and 4, the apparatus 5 includes a sampling clock generator 51, a detector unit 52, and a selector unit 53.

The sampling clock generator 51 is adapted to receive the oscillator output from the voltage controlled oscillator 44, and generates a number ( $N$ ) of sampling clock signals in response to the oscillator output. The sampling clock signals generated by the sampling clock generator 51 have the same clock frequency and different clock phases. Each of the sampling clock signals forms a relative phase difference equal to  $360/N$  degrees with another one of the sampling clock signals. While the number ( $N$ ) is equal to 6 in this embodiment, the actual number should not be limited thereto. In practice, a higher number ( $N$ ) of sampling clock signals may be set up for higher sampling precision requirements.

The detector unit 52 includes a delay circuit 521 coupled to the sampling clock generator 51, and a signal processing circuit 522 coupled to the delay circuit 521. The signal processing circuit 522 includes a sampling  
5 circuit 523 and a comparison circuit 524.

The sampling circuit 523 is constructed from D-type flip-flops F1, F2, F3, F4, F5, F6, ..., is coupled to the delay circuit 521, and is adapted to receive the input digital signal ( $S_{DATA}$ ). The sampling circuit 523 samples  
10 the input digital signal at the clock edges of the sampling clock signals to obtain multiple sampling points of the input digital signal ( $S_{DATA}$ ). Temporally adjacent ones of the sampling points are spaced apart from each other by an interval.

The comparison circuit 524 is constructed from  
15 exclusive-OR logic gates G1, G2, G3, G4, G5 and G6, and is coupled to the sampling circuit 523 for comparing logic levels of each temporally adjacent pair of the sampling points to detect the presence of a logic level  
20 transition in the input digital signal ( $S_{DATA}$ ). The logic level transition is a transition from one of high and low logic states to the other of the high and low logic states.

The selector unit 53 is coupled to the sampling clock  
25 generator 51 and the detector unit 52, and is controlled by the detector unit 52 to select one of the sampling clock signals from the sampling clock generator 51. The

selected one of the sampling clock signals has one of the clock edges thereof defining the interval that was detected by the detector unit 52 to have occurrence of the logic level transition in the input digital signal ( $S_{DATA}$ ). The selector unit 53 is further adapted to provide the selected one of the sampling clock signals to the phase detector 41 as the input phase-locking clock signal.

The operation of the apparatus 5 of this embodiment will now be described in greater detail with further reference to Figures 5 to 7.

When an optical playback system reads a blank area 611 in a header region 61 of a DVD-RAM, a corresponding signal represented by a high-level pulse ( $S$ ) is generated, as best shown in Figure 5. The playback system reads the areas 611, 612, 613, ..., in sequence to result in the input digital signal ( $S_{Data}$ ) shown in Figure 6. It should be noted herein that, while the areas 612, 613 in the header region 61 actually have data recorded therein, the contents thereof are not shown in Figure 5 for the sake of simplicity. The input digital signal ( $S_{DATA}$ ) is inputted simultaneously to the phase detector 41 of the phase-locked loop 4 and the sampling circuit 523 of the detector unit 52. At this moment, the flow of Figure 7 begins at step 31.

In step 31, the voltage controlled oscillator 44 generates the oscillator output ( $P_0$ ) that is provided

to the sampling clock generator 51. The oscillator output ( $P_0$ ) is a reference signal typically found in phase-locked loops and, as shown in Figure 6, includes a plurality of clock pulses  $U_{01}, U_{02}, U_{03}, \dots U_{07}$  for triggering operation of the sampling circuit 523.

Then, in step 32, the sampling clock generator 51 generates six sampling clock signals in response to the oscillator output ( $P_0$ ) in the following manner: A first sampling clock signal ( $P_0$ ) is generated by outputting the oscillator output ( $P_0$ ) directly. The second sampling clock signal ( $P_1$ ) is generated by introducing a delay period ( $T_d$ ) into the first sampling clock signal ( $P_0$ ). The third sampling clock signal ( $P_2$ ) is generated by introducing the same delay period ( $T_d$ ) into the second sampling clock signal ( $P_2$ ). The fourth to sixth sampling clock signals ( $P_3, P_4, P_5$ ) are generated in a similar manner. The six sampling clock signals are provided to the sampling circuit 523 through the delay circuit 521. Accordingly, the sampling circuit 523 receives clock pulses  $U_{01}, U_{02}, U_{03}, \dots U_{07}, U_{11}, U_{12}, U_{13}, \dots U_{17}, U_{21}, U_{22}, U_{23}, \dots U_{27}, U_{31}, U_{32}, U_{33}, \dots U_{37}, U_{41}, U_{42}, U_{43}, \dots U_{47}, U_{51}, U_{52}, U_{53}, \dots U_{57}$ , the total number of which is six times of that of the clock pulses of the oscillator output ( $P_0$ ). The clock pulses received by the sampling circuit 523 control the number of sampling operations to be performed by the sampling circuit 523 upon the input digital signal ( $S_{Data}$ ).

In step 33, the clock pulses  $U_{01}, U_{02}, U_{03}, \dots U_{07}, U_{11}, U_{12}, U_{13}, \dots U_{17}, U_{21}, U_{22}, U_{23}, \dots U_{27}, U_{31}, U_{32}, U_{33}, \dots U_{37}, U_{41}, U_{42}, U_{43}, \dots U_{47}, U_{51}, U_{52}, U_{53}, \dots U_{57}$  trigger the sampling circuit 523 for sampling the input digital signal ( $S_{Data}$ ) at leading clock edges of the clock pulses, thereby resulting in multiple sampling points (forty-two in this embodiment) of the input digital signal ( $S_{Data}$ ). Temporally adjacent ones of the sampling points are spaced apart from each other by an interval equal to the delay period ( $T_d$ ). The logic level of each sampling point is then outputted to the comparison circuit 524. Particularly, at the sampling point ( $P_{01}$ ) of the input digital signal ( $S_{Data}$ ), the clock pulse ( $U_{01}$ ) of the first sampling clock signal ( $P_0$ ) triggers the flip-flop ( $F1$ ) such that the logic level of the input digital signal ( $S_{Data}$ ) detected by the sampling circuit 523 is a low logic level, and a low logic signal is provided by the sampling circuit 523 to one of two input terminals of the exclusive-OR logic gate ( $G1$ ) of the comparison circuit 524. Subsequently, at the sampling point ( $P_{11}$ ) of the input digital signal ( $S_{Data}$ ), the clock pulse ( $U_{11}$ ) of the second sampling clock signal ( $P_1$ ) triggers the flip-flop ( $F2$ ) such that the logic level of the input digital signal ( $S_{Data}$ ) detected by the sampling circuit 523 is a high logic level, and a high logic signal is provided by the sampling circuit 523 to the other one of the two input terminals of the exclusive-OR logic

gate (G1) and to one of the two input terminals of the exclusive-OR logic gate (G2) of the comparison circuit 524. Likewise, at the sampling point ( $P_{21}$ ) of the input digital signal ( $S_{Data}$ ), the clock pulse ( $U_{21}$ ) of the third

5 sampling clock signal ( $P_2$ ) triggers the flip-flop (F3) such that the logic level of the input digital signal ( $S_{Data}$ ) detected by the sampling circuit 523 is a high logic level, and a high logic signal is provided by the sampling circuit 523 to the other one of the two input

10 terminals of the exclusive-OR logic gate (G2) and to one of the two input terminals of the exclusive-OR logic gate (G3) of the comparison circuit 524. Accordingly, at the succeeding sampling points ( $P_{31}$ ,  $P_{41}$ ,  $P_{51}$ ,  $P_{02}$ ,  $P_{12}$ , ...  $P_{47}$ ,  $P_{57}$ ) of the input digital signal ( $S_{Data}$ ), the

15 clock pulses  $U_{31}$ ,  $U_{41}$ ,  $U_{51}$ ,  $U_{02}$ ,  $U_{12}$ , ...  $U_{47}$ ,  $U_{57}$  of the sampling clock signals trigger a corresponding one of the flip-flops (F1-F6) such that the sampling circuit 523 is able to sample temporally adjacent pairs of the sampling points of the input digital signal ( $S_{Data}$ ), such

20 as  $P_{21}$  and  $P_{31}$ ,  $P_{31}$  and  $P_{41}$ ,  $P_{51}$  and  $P_{02}$ ,  $P_{02}$  and  $P_{12}$ , ...  $P_{07}$  and  $P_{17}$ ,  $P_{17}$  and  $P_{27}$ . Each corresponding pair of sampled logic levels is outputted to a corresponding one of the exclusive-OR logic gates (G1-G6) in preparation for detection of a logic level transition in the following

25 step 34. As shown in Figure 6, the intervals of the adjacent pairs of the sampling points  $P_{01}$  and  $P_{11}$ ,  $P_{11}$  and  $P_{21}$ ,  $P_{21}$  and  $P_{31}$ ,  $P_{31}$  and  $P_{41}$ , ...  $P_{07}$  and  $P_{17}$ ,  $P_{17}$  and

$P_{27}$  are indicated as  $R_{01}$ ,  $R_{11}$ ,  $R_{21}$ ,  $R_{31}$ , ...  $R_{07}$  and  $R_{17}$ .

In step 34, the comparison circuit 524 compares the logic levels of each temporally adjacent pair of the sampling points to determine the presence of a logic level transition. If the two logic levels are different, the flow goes to step 35. Otherwise, the flow goes to step 36. As shown in Figure 6, a logic level transition from low to high occurs in the interval  $R_{01}$  defined by the adjacent sampling points  $P_{01}$ ,  $P_{11}$ , and in the interval  $R_{07}$  defined by the adjacent sampling points  $P_{07}$ ,  $P_{17}$ . A logic level transition from high to low is present in the interval  $R_{04}$  defined by the adjacent sampling points  $P_{04}$  and  $P_{14}$ . Due to the use of the exclusive-OR logic gates (G1-G6) in the comparison circuit 524, a high-level output will be generated whenever there is a logic level transition. As such, the interval detected to have the logic level transition occurring therein can be determined in step 35. All other adjacent pairs of the sampling points that define intervals with no logic level transition occurring therein will result in the generation of a low-level output from the corresponding exclusive-OR logic gate (G1-G6).

Step 37 follows step 35. In step 37, the selector unit 53 selects one of the sampling clock signals in accordance with the exclusive-OR logic gate (G1-G6) of the comparison circuit 524 that indicated the presence of a logic level transition. As evident from Figure 6,

the intervals  $R_{01}$ ,  $R_{04}$ ,  $R_{07}$  are defined by clock edges of the clock pulses of the sampling clock signals  $P_0$ ,  $P_1$ . This indicates that either one of the sampling clock signals  $P_0$ ,  $P_1$  has a phase that is very close to that of the input digital signal ( $S_{Data}$ ). Therefore, the selector unit 53 is designed to select one of the sampling clock signals  $P_0$ ,  $P_1$  and to provide the selected one of the sampling clock signals  $P_0$ ,  $P_1$  to the phase detector 41 as the input phase-locking clock signal.

10 In step 36, as long as no logic level transition in the input digital signal ( $S_{Data}$ ) is detected, the selector unit 53 maintains a current input phase-locking clock signal to the phase detector 41.

15 In step 38, steps 31 to 37 are repeated until the current output of the charge pump 42 is zero, which indicates that the desired locked clock phase condition has been reached.

20 It is worthwhile to note that the selector unit 53 is constituted by a logic circuit and thus has an inherent delay time ( $T_1$ ). Therefore, the delay circuit 521 of the detector unit 52 can be configured to introduce the same delay time ( $T_1$ ) into the sampling clock signals  $P_0$ ,  $P_1$ ,  $P_2$ ,  $P_3$ ,  $P_4$ ,  $P_5$  before receipt of the same by the sampling circuit 523 so that the selected clock signal provided by the selector unit 53 is also delayed by the delay time ( $T_1$ ). In this sense, the apparatus 5 provides a clock signal with almost no timing error to the



phase-locked loop 4.

By following the aforesaid steps, the phase of the selected sampling clock signal, e.g.,  $P_1$ , is very close to that of the input digital signal ( $S_{Data}$ ). Therefore, when the sampling clock signal ( $P_1$ ) is used as the current phase-locking clock signal for the phase-locked loop 4, the phase-locked loop 4 only needs to adjust the phase difference between the input digital signal ( $S_{Data}$ ) and the sampling clock signal ( $P_1$ ) in order to achieve the desired locked clock phase condition within a very short amount of time.

Moreover, as shown in Figure 5, when the optical playback system reads another blank area 615 in a header region 61 or other blank areas 622, 623 in a record region 62 of the DVDRAM, a corresponding signal represented by the high-level pulse (S) will be generated for triggering the apparatus 5 of this invention to perform the aforesaid method for enabling fast clock phase locking in the phase-locked loop 4.

While the present invention has been described in connection with what is considered the most practical and preferred embodiment, it is understood that this invention is not limited to the disclosed embodiment but is intended to cover various arrangements included within the spirit and scope of the broadest interpretation so as to encompass all such modifications and equivalent arrangements.